Fraunhofer Diffraction at a Slit

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1 Introduction and Theory

Diffraction is the phenomenon by which freely propagating light spreads out into a region beyond an aperture or obstacle and is one of the four main characteristics of a wave. There are two different types of diffraction: Fraunhofer diffraction and Fresnel diffraction. Fraunhofer diffraction is ultimately long range diffraction, and in order to study it experimentally, parallel wavefronts are directed at a diffraction object; a slit in the case of this experiment, so that we can consider the light to be diverging from a source which is at an infinite distance from the slit. Experimentally, this is achieved using a combination of converging lenses. The light from the laser is directed through a converging lens of very small focal length (5mm in this case) so that the rays converge at the focal point and create a point source before diverging outwards again. This light is then passed through another converging lens of larger focal length (100mm) which is placed roughly 10.5cm in front of the first lens. The idea of this set up is to have the focal points of both lenses at the same point in space, such that all light rays coming from the point source created by the first lens go through the focus of the second lens, and thus emerge as parallel rays.

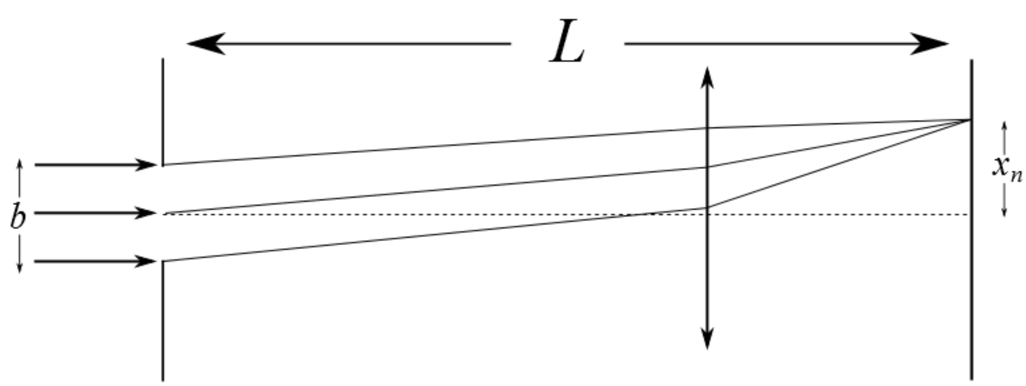

Figure 1: Fraunhofer diffraction at a slit.

Fresnel diffraction involves a light source and a screen at finite distances from the slit. The calculations associated with Fraunhofer diffraction are simpler than those associated with Fresnel diffraction.

Using another converging lens placed after the slit, the diffraction of parallel light rays at the slit produces a diffraction pattern of light and dark fringes which can be analysed using a radiation measuring instrument called VideoCom. This piece of apparatus, when connected to a PC, outputs a plot of incident light intensity versus position in pixels. Such a graph is ultimately a plot of the diffraction pattern and allows us to easily calculate the distances between corresponding minima. When analysing the pattern of maxima and minima, the condition associated with finding a minimum is

$$b \sin(\phi) = n\lambda, \quad n \in \mathbb{N} \tag{1}$$

where b is the slit width, ϕ is the angle of diffraction, λ is the wavelength of light involved and n is the order of the minimum. For small diffraction angles, we can make the approximation $\sin(\phi) \approx \tan(\phi) \approx \phi \approx \frac{x}{L}$, and hence

$$b\frac{x}{L} = n\lambda, \tag{2}$$

where x is the distance between two minima of the same order.

It is thus possible to calculate the slit spacing from this formula, provided a monochromatic light source is used and the distance L between the slit and the screen can be measured. The relationship between order and distance between two minima of the same order can also be investigated by varying the slit width and plotting x versus $\frac{1}{b}$. Clearly b and x are inversely proportional, so such a graph should in theory yield a straight line of slope $\frac{nL}{\lambda}$.

It is also possible to go about this experiment from the opposite direction and calculate the slit width from the diffraction pattern and the formula above.

2 Experimental Method

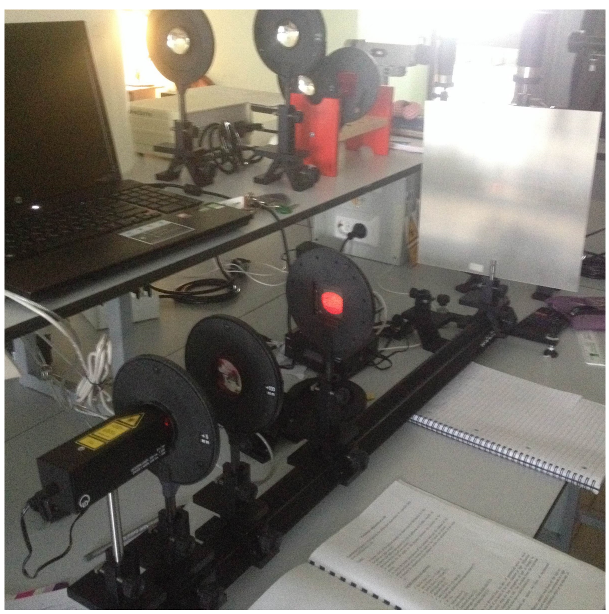

Figure 2: Experimental setup.

In part one of this experiment, in order to observe a diffract pattern, a combination of converging lenses, a polariser and a slit with changeable width were positioned on an optical bench along with a HeNE laser and a VideoCom radiation detector connected to a PC. The helium neon laser was mounted on the optical bench and turned on. A spherical lens of focal length +5mm was placed in front of the laser on the bench at a distance of roughly 1cm. The height of the lens was adjusted until the beam of the laser fell directly on the centre of the aperture. A second converging lens of focal length +100mm was placed behind this lens at a distance of roughly 10.5cm from the first lens and the height of the lens was adjusted accordingly. A screen was then added to the optical bench at the opposite end. The second lens was moved slowly back and forth on the rail until a position was found such that the laser beam which focuses on the screen had a diameter of roughly 6mm and the beam had a constant circular profile along the optical axis. This was checked by holding a piece of paper between the second lens and the slit and moving it back and forth along the optical axis. When it was determined that the beam had a constant diameter, clearly this meant that the rays emerging from the second lens were parallel and the focal points of the two lenses had roughly overlapped in space. A polarisation filter was then placed after the second lens, and an adjustable slit also added to the rail after the polariser. Finally the VideoCom radiation detector was added in the place of the screen and connected to the PC. The programme videocom intensities was used, and the two scales on the VideoCom detector were set respectively to 1.8 and inf. Measurements of Intensity and position in pixels were obtained and were outputted by the programme as a plot. The function of the polariser was to vary the intensity of light reaching the VideoCom. Finally a lens of focal length +50mm was added in front of the VideoCom detector in order to bring the rays together so that a diffraction pattern formed on the lens of the detector. The polariser was adjusted such that the intensity of light reaching the slit was not too overwhelming and a diffraction pattern was outputted on the PC. The width of the slit was varied and the different diffraction patterns were observed. The distances between the two second minima for each slit width was measured in pixels.

In part two of this experiment, the same apparatus set up was used. The slit width was set to 0.6mm using the scale on the back of the adjustable slit and the resulting diffraction pattern was observed on the PC. The distance was measured (in pixels) between the minima for $n = 1,\ 2,\ 3$. For $n > 3$, the minima were no longer clearly defined.

In part three of this experiment, the diffraction pattern was observed on the screen instead of the VideoCom detector, and so the VideoCom, the polariser and the third lens were all removed from the set up and a screen was re-added to the optical bench. The adjustable slit was also removed and replaced by a holder with spring clips, into which a diaphragm with three slits of fixed width was placed. Two of the three slits were blocked at a time, and the diaphragm was adjusted such that the laser beam fell directly on the chosen slit. A diffraction pattern resulted on the screen and a piece of paper was put on the screen such that the positions of the first two minima could be drawn on the paper and thus the distances between the first two minimum could be measured.This was repeated for each of the three slits. The distance L between the slit and the screen was also measured using a ruler.

3 Results and Analysis

In the first part of the following distances were recorded for various slit widths:

Slit spacing b (mm)	Distance between minima $2x_n$ (pixel)
0.2	232
0.4	104
0.6	56
0.8	44

By plotting x_n vs $\frac{1}{b}$, a straight line graph was obtained with slope $m = 0.039 \pm 0.001$ and intercept $c = 0.48 \pm 0.08$.

The following distances were recorded for different order fringes, as well as the distance to order ratio:

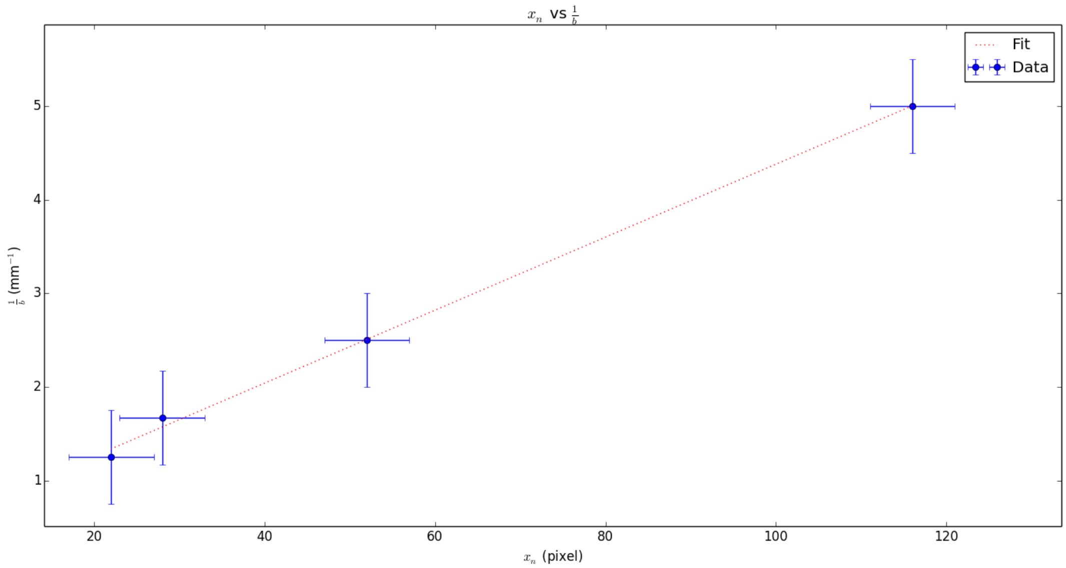

Figure 3: Graph of x_n vs $\frac{1}{b}$.

Order n	Distance between minima $2x_n$ (pixel)	$\frac{x_n}{n}$ ratio
1	100	100
2	156	78
3	220	73.3
4	284	71

4 Discussion and Conclusions

In part one of this experiment we verified the linear relationship between slit width and the distance of any minima to the centre of the diffraction pattern. This was achieved by plotting the distance x_n from the centre of the pattern to the first minima against the inverse of slit width. A straight line graph was obtained.

In part two of the experiment, the relationship between the order of the minimum and its distance to the centre of the pattern was investigated. It was observed quantitatively that as the order of the minima increases, the distance from the minima to the centre of the pattern increases. This relationship becomes obvious by simply looking at our table of results and was demonstrated clearly by our plot of order of the minima versus distance of these minima to the centre of the interference pattern.

The third part of the experiment was not completed due to the inaccuracy of our results.

There were many possible sources of inaccuracy in this experiment. Firstly, the apparatus set up was very precise and involved a number of elements, any of which could easily have been slightly misaligned and so could have introduced errors in our results. Secondly, the radiation detector was very sensitive to noise. One of the group members was forced to stand between the apparatus and the window in an attempt to shield the detector from background light. This was not a very thorough way of removing background noise which could easily tamper with our results, however no other method of shielding the detector from light was plausible.

Finally, in part three of the experiment, the locations of the first minima were marked on a sheet of paper for each of the three diffraction gratings and the distances between them were measured using a ruler. This meant that we were taking small measurements on the mm scale with an error of ± 1mm.